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(54) A method of non-destructive testing of structural members

(57) A method for the non-destructive testing of fibre-reinforced composite materials by means of monochromatic X-ray examination and detector image formation in which the method comprises examining the structure by X-ray microstructure examination and determining its variation in position and form of X-rays 3 scattered in image formable reflections by the polycrystalline material as a measure of variations and internal stresses in the test piece 4.

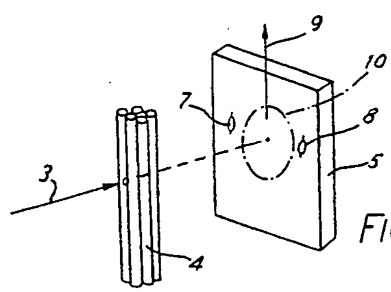

FIG. 2

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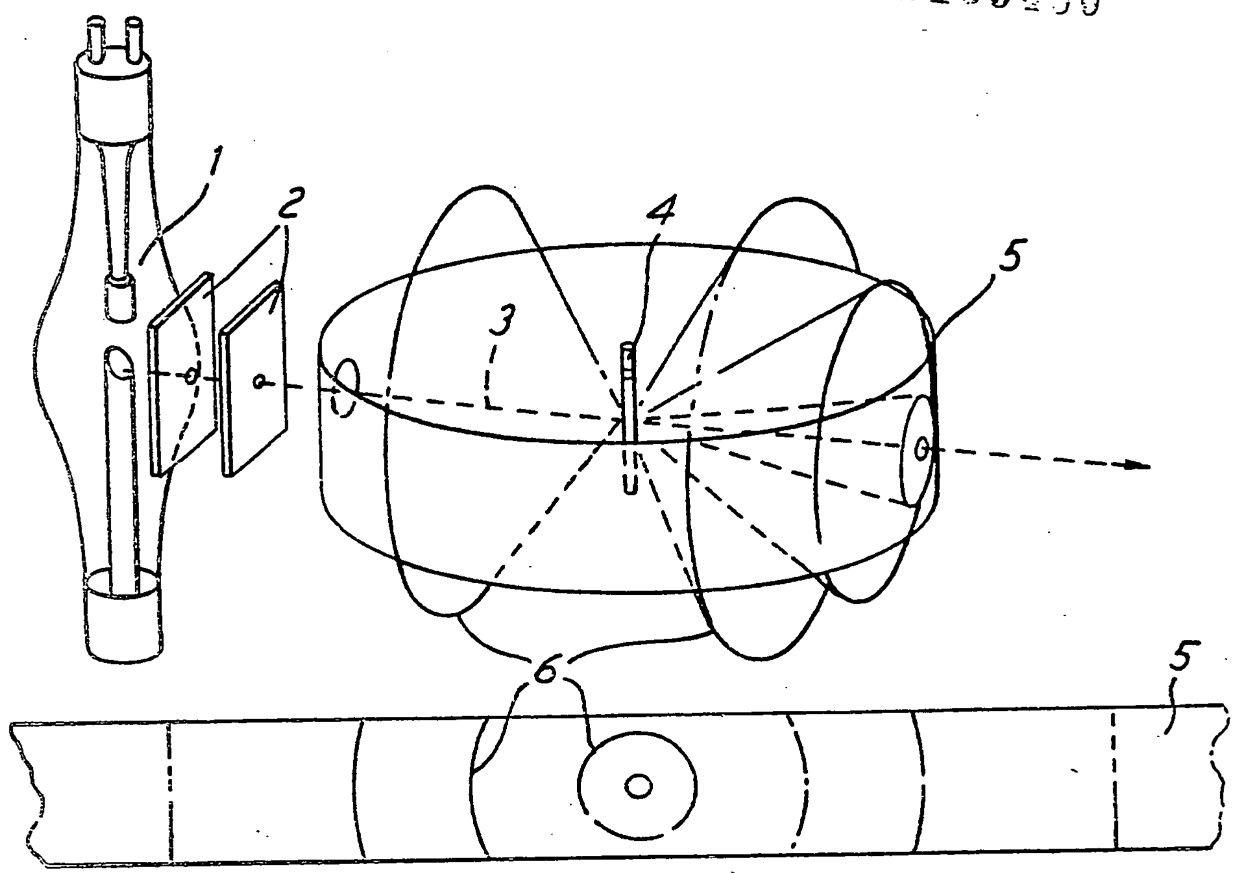

FIG.1

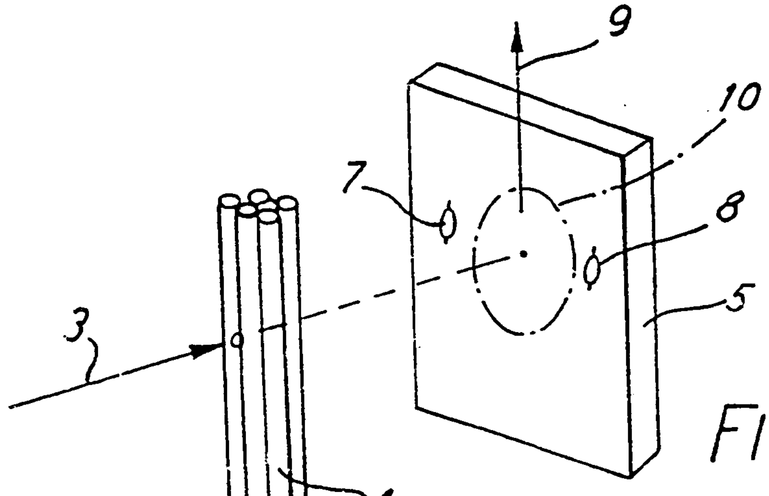

FIG.2

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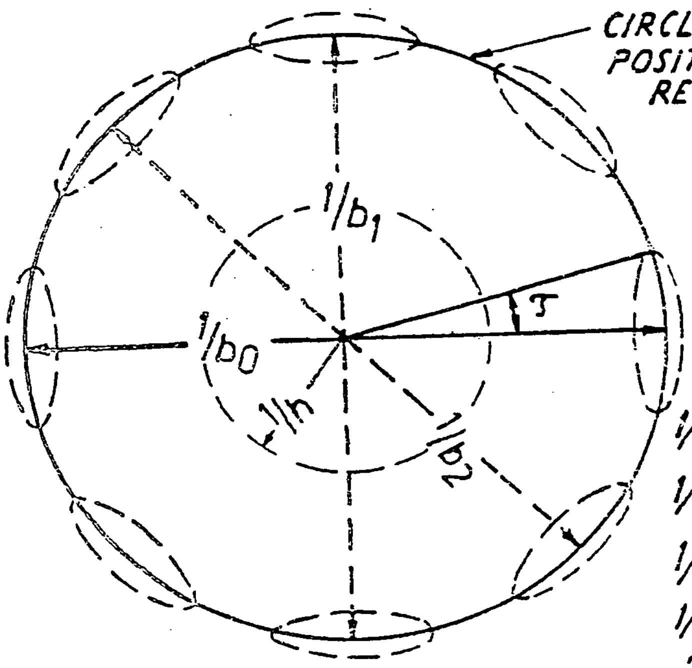

FIG. 3

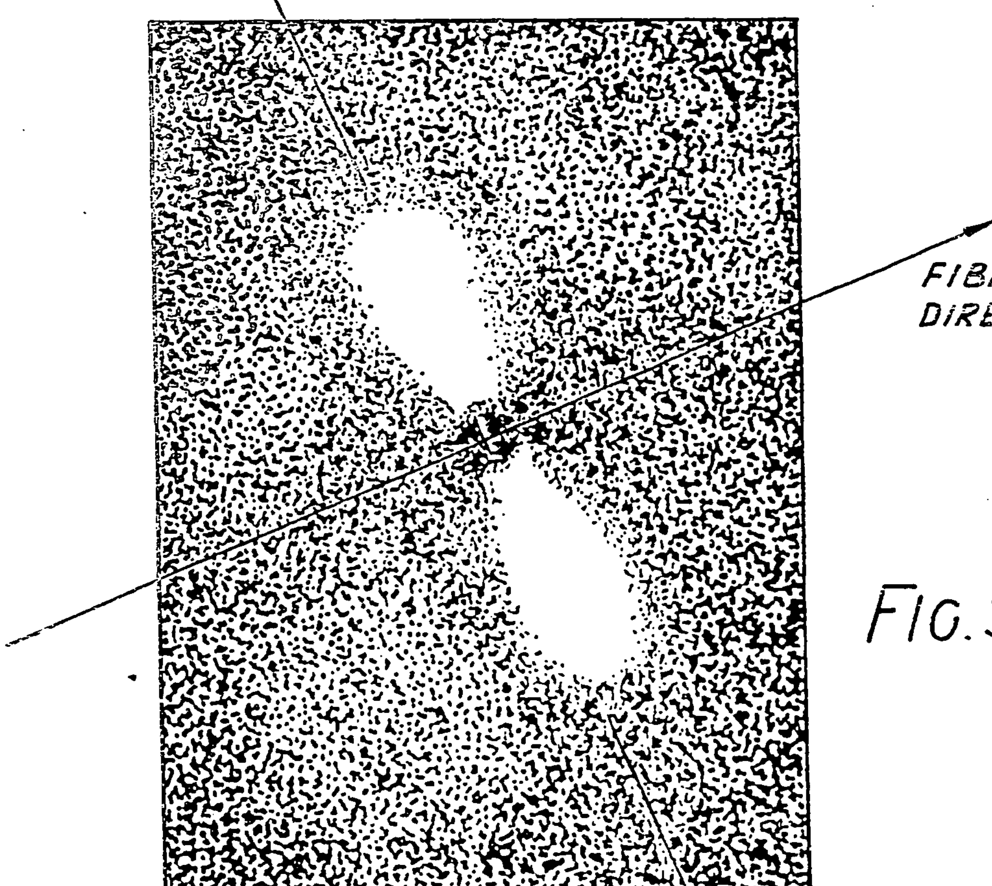

FIG. 5

fore only produces circular reflections 10 as indicated in Figure 2.

As can be seen from the illustration of Figure 3, the reflections of a carbon-fibre composite system examined may, for example, assume the positions reproduced in this figure. In this case, it is a question of the so-called 002 reflections of the carbon with different fibres and angular directions of a composite system and of the halo of the resin surrounding the fibres. The spacing b of two adjacent graphite lattice planes 002 of a composite system is related to the reflection distances from the zero point, which in first approximation are reciprocal to the spacing b of the lattice planes, that is to say they are reproduced with a spacing $\frac{1}{b}$ on an X-ray diagram. In the illustration shown in Figure 3, the reflections with the index 0 indicate fibres which lie in the verticals of the drawing plane. Reflections with the index 1, that is to say $\frac{1}{b}_1$ on the other hand, indicate fibres which are orientated perpendicular thereto.

In the case of these reflections, the position of the reflections may also fluctuate by ± 5°. The reflections with the index 2, that is to say $\frac{1}{b}_2$, indicate fibre orientations in the diagonal direction. 2γ indicates the half width of the reflections in the tangential direction. It is a measure of the quality of the parallel orientation of the microparacrystals in th fibre direction and depends on the structure of a fibrel (individual fibre) and on the quality of the shift of the rod. $\frac{1}{R}$ indicates the position of the resin without any orientation direction.

It is possible to draw conclusions about the nature of the fibre orientation in a structural member of composite materials examined, from the position of the reflections. In this case, the tangential half-width (half angle γ) of the $\frac{1}{b}$ reflections is a measure of the quality of the fibre windings, thus a measure of the degree of orientation of the corresponding fibres.

During the examination of fibre-reinforced composite materials, the following measuring effects can be found as well as the results which can be derived therefrom.

	Measurement	Effect caused by	Evidence of
1	Intensity of the reflection	Number of lattice planes (microparacrystals) in the test piece (proportional)	Number of fibres per unit of area dependent on type of fibre
2	Angle of the reflection to an axis of symmetry of the test piece	Position of the normals of the lattice planes to the fibre axis	Position of the fibre direction to the axis of symmetry of the test piece (winding direction)
3	Azimuthal width of the reflection	Scattering of the position of the lattice planes	Orientation of the fibres
4	Radial spacing of the reflections	Lattice plane spacing	Type of material (sorts of fibre) internal stress, purity
5	Radial width of reflection	Paracrystalline disturbances and size of the micro-paracrystals	Impurities; density of internal surfaces, mechanical stability
6	Halo of metallic coatings (aluminium)	Randomly distributed lattice planes of vapour-deposited crystals	Thickness of layer and purity of the protective coatings
7	Halo of the sorts of resin	Random masses of molecules	Genuineness of the sorts of resin + type

As the following illustrations show, various statements with regard to the test pieces examined can be made using this measuring technique. Thus Figure 4, for example, shows a halo which can be interpreted as an index of a resin system without fibres. The spot in the middle of the halo and the interruption of the halo result from the lead diaphragm to mask the primary X-ray.

Figure 5 shows the reflections of a fibre-reinforced composite system and the orientation of the fibres on the basis of the reflections reproduced.

Figure 6 likewise shows reflections of a fibre-reinforced composite system examined, with fibres orientated in a plurality of directions.

The method according to the invention therefore enables fibre-reinforced composite materials to be examined non-destructively by means of X-rays and enables the results of the examination to be interpreted satisfactorily. In this case, a source having a plurality of ray exit windows may be used for the X-ray source, and the ray exit windows for the primary rays and the reflections may have different diaphragm shapes (triangle, circle, star, square, etc) adapted to the composite pattern in each case. An X-ray film may be used as the detector with the possibility of masking certain reflections or parts of reflections by diaphragms for checking purposes. Electronic and/or scintillation counters provided with preceding special diaphragms and able to be positioned appropriately may be used, with recording devices, as detectors. These special diaphragms may also be aligned in the direction of the bundles of fibres, for example in the form of slits, in order to achieve greater intensities. It is also possible, however, to provide the detectors which can be positioned with automatic focussing devices to align the detectors in positions of maximum X-ray intensity.

In another form of embodiment, the test piece and the detector system may be moved in relation to one another while in a further form of embodiment a test piece consisting of composite material can be conveyed past a stationary detector or film, using a stationary X-ray source in order to test the total quality of the test piece.

When the method according to the invention is used for tubular test pieces, these may be rotated continuously about their longitudinal axis in order to test the uniform coverage of the wound composite fibres as to their cross-sections and/or their total number. In this case, the tubular test pieces may be moved past a stationary detector with a helical and/or meandering movement, the X-ray tube being situated at one side and the detector at the other side of the test piece. In the case of an X-ray tube constructed in rod form, it is also possible to dispose this inside a tubular test piece.

The evaluation of the measurements can be affected in continuous operation by simultaneous measurement of a plurality of, but at least two, reflections in an electronic differential circuit. In this case, it is also possible to record two base reflections (002) of a carbon fibre or of a polymer fibre using a narrower and a wider diaphragm in a differential connection and to regard the difference in width resulting parallel to the fibre as information regarding the quality of the degree of orientation of the microparacrystals inside a fibre strand. In this connection, the difference in width of the diaphragms may be perpendicular to the fibre direction of the test piece and provide information about the size and lattice imperfections of the microparacrystals of the fibres. Two reflections of different fibre strands detected in a differential circuit may also count as information with regard to the constancy of the fibre thickness or fibre strength on the basis of the mass of the microparacrystals in each thread cross-section.

Apart from evaluating the fibre thicknesses, the fibre direction and laying quality, it is also possible to record the proportion of randomly distributed molecules, particularly of fillers or binders, by a stationary measurement with an X-ray film or by adjustment of the counting apparatus used to the halo in question and to carry out an evaluation, for example by means of photometric evaluation. By this means, it is also possible to obtain information about the quality of the filler, for example resin.

In a further development of the invention, it is also possible to replace the recording device by an alarm device which releases a signal when a tolerance value of the measured quantities or differential quantities is exceeded. The alarm device may also have a device for position marking associated with it in order to mark the positions on the test piece at which the alarm is activated during continuous checking.

The method according to the invention has a special application to composite fibre materials but it can also be used for testing vehicle tyres, particularly for testing the tyre carcases.

CLAIMS

1. A method of non-destructive testing of structural members of fibre-reinforced composite materials by monochromatic X-ray examination and detector image-formation, wherein the method comprises examining the structure by X-ray microstructure examination and determining the variation in the position and form of the X-rays scattered in image-formable reflections by the polycrystalline material as a measure of variations and internal stresses of the test piece.

2. A method as claimed in Claim 1, wherein an X-ray source is used having a plurality of ray exit windows and the ray exit windows for the primary rays and the reflections have different diaphragm shapes adapted to the composite pattern in each case.

3. A method as claimed in Claim 2, wherein the shape of the diaphragms are triangular, circular, star shaped or square.

4. A method as claimed in Claim 1, 2 or 3, wherein an X-ray film is used as the detector and diaphragms are used to mask certain reflections or parts of reflections for checking purposes.

5. A method as claimed in Claim 1, 2 or 3, wherein detectors are used which comprise electronic and/or scintillation counters, which can be appropriately positioned, have special preceding diaphragms and have recording devices associated therewith.

6. A method as claimed in Claim 5, wherein the special diaphragms are aligned in the direction of the bundles of fibres in order to achieve greater intensi-

ties.

7. A method as claimed in Claim 6, wherein the special diaphragms are in the form of slits.

8. A method as claimed in any one of the Claims 1 to 7, wherein detectors which can be variably positioned are used, the detectors having automatic focussing devices for aligning the detectors in positions of maximum X-ray intensity.

9. A method as claimed in Claim 8, wherein a test piece comprising composite material is moved relative to a detector or film associated with an X-ray source, for testing the quality of the whole object.

10. A method as claimed in Claim 9, wherein the test piece is conveyed past a stationary detector or film and associated stationary X-ray source.

11. A method as claimed in any one of Claims 1 to 9, wherein the test-piece and detector system are moved continuously.

12. A method as claimed in any one of Claims 1 to 9, wherein tubular test-pieces are rotated continuously about a longitudinal axis to test the uniform coverage of the wound composite fibres as to their cross-section and/or their total number.

13. A method as claimed in any one of Claims 1 to 12, wherein a tubular test piece is moved past the stationary detector with a helical and/or meandering movement and the X-ray tube is situated at one side of the test piece and the detector is situated at the other side of the test piece.

14. A method as claimed in Claim 12 or 13, wherein the X-ray tube is rod-shaped and is disposed inside the tubular test piece.

15. A method as claimed in any one of Claims 1 to 14, wherein a plurality of reflections are measured and evaluated simultaneously in an electronic differential circuit, in continuous operation.

16. A method as claimed in any one of Claims 1 to 14, wherein two base reflections (002) of a carbon fibre or two base reflections (110,200) of a polymer fibre are recorded with narrower and wider diaphragms in a differential connection whereby the difference in width existing parallel to the fibre provides information concerning the quality of the degree of orientation of the microparacrystals inside a fibre strand.

17. A method as claimed in any one of Claims 1 to 15, wherein two base reflections (002) of a carbon fibre or the base reflections (110,200) of a polymer fibre are recorded with two diaphragms, one of which is narrower and the other of which is wider perpendicular to the fibre direction, in a differential connection whereby the difference in width provides information regarding the size and lattice imperfections of the microparacrystals of the fibres.

18. A method as claimed in any one of Claims 1 to 16, wherein two reflections of different fibre strands detected in a differential circuit provide information with regard to the constancy of the fibre thickness or fibre strength on the basis of the mass of the microparacrystals in each thread cross-section.

19. A method as claimed in any one of Claims 1 to 16, wherein the proportion of randomly distributed molecules, such as fillers or binders is recorded by stationary measurement with X-ray film or by adjusting a counting apparatus to the halo in question and an evaluation which can be carried out by means of photo-metric evaluation renders possible a statement of quality of the particular filler binder etc.

20. A method as claimed in any one of Claims 1 to 19, wherein the recording device is replaced by an alarm device which produces a signal when a tolerance value of the measured quantities or differential quantities is exceeded.

21. A method as claimed in Claim 19, wherein the alarm device has a device for position marking associated with it in order to mark the positions on the text piece at which the alarm was activated during continuous checking.

22. A method of non-destructive testing of structural members of fibre reinforced composite materials substantially as described herein with reference to the drawings.

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